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of the
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**NATIONAL ACADEMY OF SCIENCES—
NATIONAL RESEARCH COUNCIL**

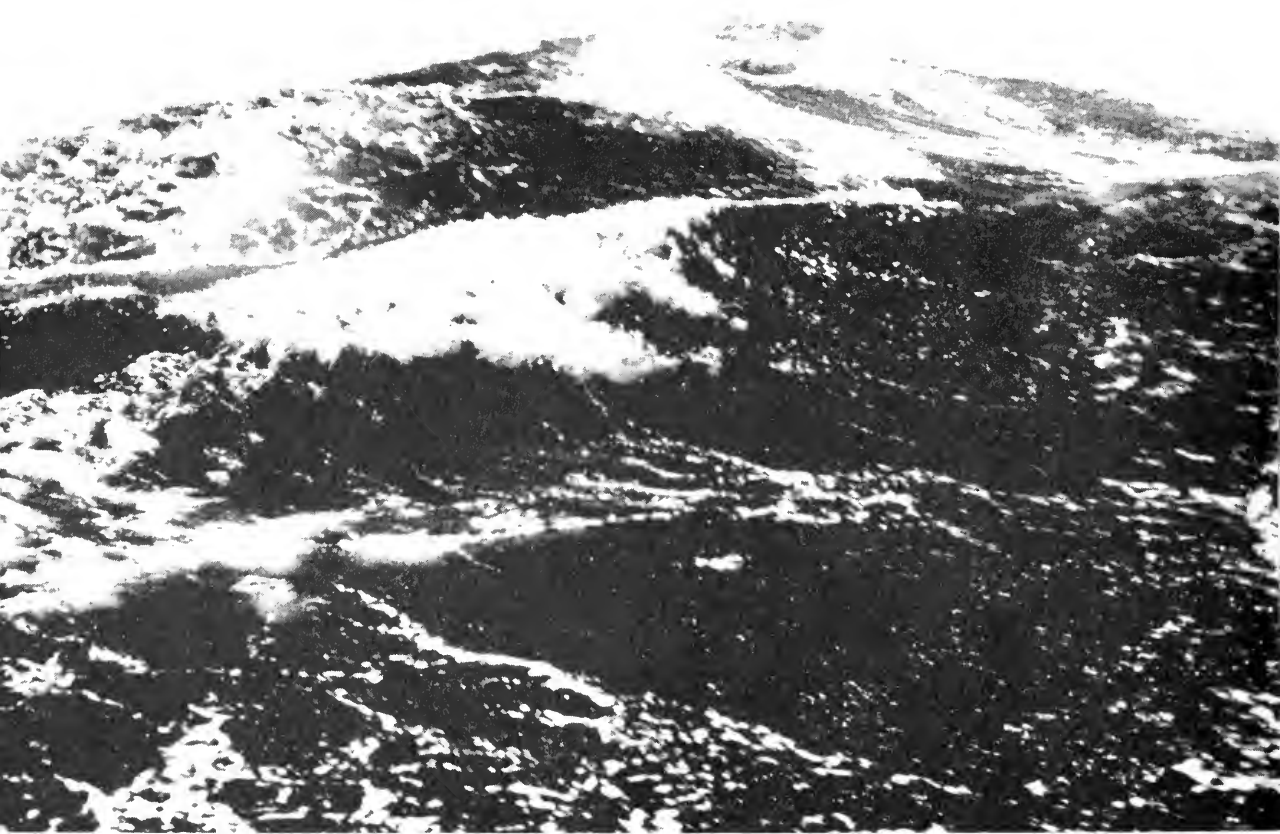
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OCEANOGRAPHY 1951



Oceanography 1951

A report on
the present status of
the Science of the Sea

by

THE COMMITTEE ON OCEANOGRAPHY

of the

NATIONAL ACADEMY OF SCIENCES

NATIONAL ACADEMY OF SCIENCES — NATIONAL RESEARCH COUNCIL
Washington, D. C.

1952

. . . *When I have seen the hungry ocean gain
Advantage on the kingdom of the shore,
And the firm soil win of the watery main,
Increasing store with loss and loss with store . . .*

—SHAKESPEARE, SONNET LXIV

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PREFACE

IN 1927, the National Academy of Sciences authorized the appointment of a committee to consider the share of the United States in a world-wide program of oceanographic research. Prior to that time, leadership in this science was clearly vested in the countries of Europe bordering on the North Sea. In this country, oceanographic studies had been pursued largely incidental to the practical tasks of several governmental agencies (Hydrographic Office, Coast and Geodetic Survey, Coast Guard, and Bureau of Fisheries) or on the initiative of a few private individuals such as Alexander Agassiz and Henry B. Bigelow.

The report prepared by the earlier Committee on Oceanography brought recognition to the science of the sea. Substantial sums were forthcoming for buildings, vessels, and endowment for institutions on the east and west coasts, which were adequate for the time. With the onset of World War II, practical applications of oceanography were recognized by the Armed Forces and funds became available for oceanographic work of all sorts. After the war, inflation made it impossible to continue oceanographic research on the pre-war scale with-

out additional support. The government has continued to provide this. Nevertheless the healthy growth of oceanography has been hampered by the uncertainty as to how long this support may be available, and by other restrictions.

As this was a situation common to all oceanographic institutions, the late Dr. Frank B. Jewett considered it timely to establish a second Committee of Oceanography to review the needs of this science today. Accordingly, the President of the National Academy in 1949 established such a committee. The following report is the result of its deliberations.

The Committee consisted of Detlev W. Bronk, Chairman, L. O. Colbert, Carl Eckart, W. Maurice Ewing, Richard H. Fleming, A. G. Huntsman, Columbus O'D. Iselin, Frank B. Jewett, Alfred C. Redfield, F. W. Reichelderfer, Roger Revelle, Louis B. Slichter, Edward H. Smith, John T. Tate, Harden F. Taylor, T. G. Thompson, Merle Tuve, and L. A. Walford.

The Committee is greatly indebted to Dr. Mary Sears for editorial aid in the preparation of this report.

INTRODUCTION

IN MOST ATLASES the oceans are shown as monotonously uniform expanses, but contrary to such indications they are far from simple. Not shown on ordinary charts are the mountain ranges and canyons on the floor of the ocean. These hidden features of the earth's solid surface contain records of its past as important as any that have been deciphered from exposed rocks. In the deep ocean far from shore, sediments are deposited with extreme slowness, so that a thickness of a few feet may reveal the earth's history over a long period. Near shore, sediments are being deposited today in the same manner as were the sediments of past geologic ages which are now exposed on the continents. Study of marine sediments therefore yields many clues to the interpretation of the geologic record.

The ocean and the atmosphere together are an enormous heat engine which is more complicated, in some ways, than any artificial engines that drive our factories. Almost none of the engineer's theoretical simplifications and approximations may be applied to the physical motions of matter and heat in the ocean. The huge scale of the current systems and of the motions resulting from frictional forces, as well as the effects of the earth's rotation, make it very difficult to use the results of hydraulic laboratories to advance our understanding of oceanic circulation.

There are four principal kinds of movement of ocean water, probably not entirely independent of one another: (1) *Surface waves*, generated by the winds, which travel great distances, so that waves produced by storms in the South Pacific may break on the California coast. (2) *Tides*, caused by the gravitational action of the moon and sun. (3) *Surface currents*, such as the Gulf Stream, caused in part by steady winds like the Trades, but strongly influenced by the earth's rotation, as well

as by the boundary between land and sea. (4) The *deep circulation* maintained by temperature and salinity differences, dependent on climatic conditions over various parts of the seas.

Not only is the interaction of the atmosphere and ocean apparent in the wind-driven currents and surface waves, but conversely the ocean is the source of much of the water that falls as rain. It is also an enormous reservoir of heat that influences climate. Consequently, meteorology and oceanography are and will continue to be strongly interdependent sciences.

Sea water is a complex chemical system that has greatly influenced the evolution of life. It contains almost all of the chemical elements, many of which take part, even in extreme dilution, in biological and other processes as diverse as the growth of plants and the cementation of loose sand into sandstone. Rainfall and evaporation of water at the sea surface and the run-off from the land both tend to change the chemical composition of sea water locally. Despite this, the relative proportions of its major constituents are almost constant over the whole world and at all depths.

The ocean supports a fauna and flora at least as varied as those of dry land. Plants grow in the upper layers of the sea penetrated by bright sunlight. Many of them, microscopic in size, float at sea in the surface waters. Despite their small size, their total photosynthetic activity is many times that of all the fields and forests of the land. About a thousand feet below the sea surface, in almost every latitude and longitude, there is another water layer in which life is apparently very abundant. The nature of these deep-living organisms is at present only a matter for speculation. Even the abyssal depths of the ocean support life, as has recently been re-emphasized through submarine photographs of the

deep ocean floor showing the tracks of numerous animals. Because organisms exist throughout the ocean, and not merely at its surface and bottom, it has many times the living space of the continents.

The end of all life is death and decay. Paradoxically, decay is itself brought about by microbial life, which converts the fragments of earlier life into chemical nutrients that can be utilized again in the growth of plants. On land, decay occurs in the surface layers of the soil, where roots of plants absorb the chemicals that are later utilized upon exposure to light in the leaves. In the ocean, the dead organisms drop, perhaps several miles, through the water; at all depths they are attacked by processes of decay, and finally the remains reach the ocean floor. In some areas there is so little free oxygen on the bottom that the bacteria familiar to the agriculturalist cannot live; yet the mud stinks from the action of anerobic bacteria. The nutrients thus produced in deep water must be transported upward again, and perhaps horizontally for thousands of miles, before they reach the illuminated layers of the sea where plants can grow through photosynthesis. Consequently, the entire gigantic heat engine of the ocean must work in order that the smallest of its floating plants may grow.

Such interrelations as those just outlined between the sciences of the sea give them a unity which justifies the use of the single term *oceanography* to embrace them all. The basic problems mentioned above do not exhaust the list of studies of the ocean that can and should be made. The economic and social problems of the sea have great practical importance.

The sea is a source of food, but compared to modern agriculture the fisheries of the world remain undeveloped. In its broadest terms, the problem is to obtain a maximum yield of food from each acre of sea surface. No reliable estimates can yet be made, but the yield is certainly much greater than that now being obtained.

The practical importance of submarine geology is just beginning to be realized. Oil occurs almost exclusively in marine sedi-

ments, and many other commercial minerals have a marine origin. The study of very recent marine sediments supplies much information about the conditions under which such deposits were formed, and is proving an increasingly useful guide in their discovery.

The oceans carry a large traffic of ships. The rapid development of airlines may possibly challenge their importance for passenger travel, but it is certain that the great volume of transoceanic freight will continue to be waterborne. Increased knowledge of the sea can help in many ways to speed this traffic, to make it safer and more economical. Likewise the military importance of ocean transport in time of war, and its vulnerability to attack by submarine, also present problems for the oceanographer to study.

The United States has accepted worldwide responsibilities in social, economic and political matters. To meet these, it must look beyond its own borders. The ocean is no longer a barrier but rather a medium that connects this continent with all other lands. It is an important source of food, actual and potential, for the whole world. Any expansion of the fishing industry will take it farther out to sea, and bring international problems with it. Consequently one part of the new responsibility of the United States is the active investigation of the oceans on a scale comparable to that of previous study of the resources within our continental boundaries.

It is the purpose of this report to review briefly the resources in facilities, personnel, and income available in this country for the support of oceanographic research, and to discuss some of the difficulties which must be overcome if our knowledge of the ocean is to be advanced for the benefit of mankind. Because of increasing specialization in oceanography, the comprehensive teaching of the subject at a university will require the organization of a small department. The demand for trained people will probably remain small, so that few universities will be willing to maintain an adequate department of oceanography. More-

over, the subject breaks across the traditional lines of university organization in that, like geology, it attempts to apply all scientific techniques to the study of a particular environment. For these reasons it is desirable that oceanographic laboratories be able to maintain small faculties and at the

same time to provide a center with facilities for scientists from other institutions who desire to undertake marine investigations. It is the longer range aspects of the science that are difficult to provide for at present and which cause the chief concern today.



RECENT ACCOMPLISHMENTS IN BASIC OCEANOGRAPHIC RESEARCH

THE MAJOR scientific accomplishments in oceanography over the last twenty years not only reflect the achievements of the earlier Committee on Oceanography but also provide for speculation as to future trends. A considerable impetus was given to work on instrumentation and applied oceanography as a result of the war, when for the first time sufficient funds were available. Work on a greatly expanded scale made it necessary to recruit scientists from allied fields: physics, geology, geophysics, meteorology, etc. A number of these, as well as several officers with scientific background from both the Army and Navy, were indoctrinated at one or another of the oceanographic laboratories, and have elected to remain in oceanography. These and others trained in recent years form a nucleus of 80 to 100 physical oceanographers in this country, compared with perhaps a half dozen prior to 1930. This is a contribution to the progress of oceanography not to be overlooked.

THE PHYSICS OF THE SEA

On the whole, physical oceanography has been advancing much more rapidly in recent years than any of the other branches of the subject. Not until the physical characteristics had been described in a realistic and detailed manner was it possible to formulate the problems in physical oceanography except in a vague way. In the last twenty years a great quantity of data has been amassed. The accumulation of subsurface temperature and salinity observations off both coasts of the United States is now comparable to that collected prior to World War II in the North Sea and off Japan. As a result, it now becomes apparent that the concepts of the oceans based on the work of the earlier expeditions have been greatly oversimplified. With the information we now have, a few limited

areas of the oceans can be reliably described. This knowledge, a major contribution in itself, formed the basis for the outstanding textbook on oceanography written during this period, *THE OCEANS*, by Sverdrup, Johnson, and Fleming. The compilation of these data together with the development in instrumentation was preliminary to still more recent theoretical advances and to greatly improved tactics in field work.

The amassing of temperature data has been much facilitated of recent years by the development of the bathythermograph, a practical diving thermometer for use from a ship underway at normal speeds. For depths down to about 300 meters it is now possible to obtain the detailed temperature-depth curve as frequently as may be advisable. As a result a research vessel can be maneuvered to follow any particular thermal feature. This technique has been particularly effective in tracing the boundaries of currents—which, contrary to earlier ideas, have been found to follow a tortuous course. The bathythermograph is also greatly facilitating the accumulation of data on the heat exchange between the ocean and the atmosphere, both seasonally and in its variations from year to year.

The advantages of the bathythermograph as a means of estimating the refraction effects in acoustical transmission near the surface were so great that funds were quickly provided by the Navy for the development of other instruments for similar purposes. One of these, a salinity-temperature-depth recorder, provides a rapid means for surveying shallow coastal waters, often so complex and variable that a true understanding of them could not be obtained with older methods. Already a significant start has been made on estuarine flushing problems using this and other continuous recording instruments.

New methods for measuring the surface temperatures and currents, together with more precise methods of navigation, have revolutionized our concept of the Gulf Stream. Analysis of older observations suggested that it was a broad, sluggish current, with a rather stable course, but it has proven to be much narrower and to have large eddies that form and disappear along its boundaries. Still more recently, mathematical analysis has given new insight into the dynamic interactions that cause it. A balance of the forces resulting from the east-west winds, the rotation of the earth, and the dissipation of energy in the form of variable eddies, causes oceanic currents to concentrate in narrow regions on the western sides of the oceans. The currents on the eastern sides, in contrast, may be much broader and less well defined.

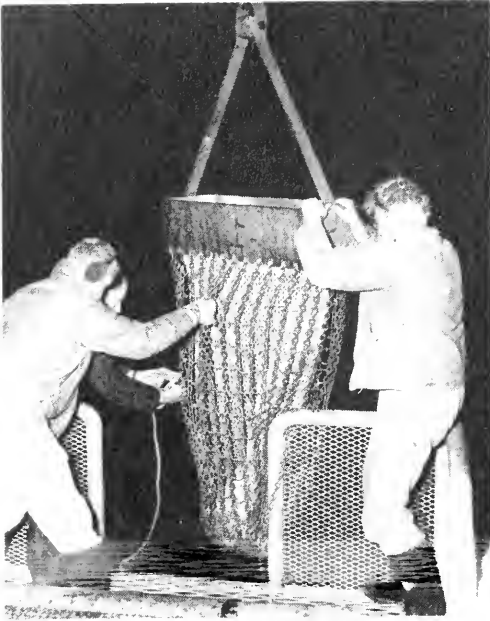
The theoretical approach also appears to afford a means for obtaining a unified hydrodynamic theory of physical oceanography. In the early work, fluids were usually assumed to be homogeneous. Stratification due to the change in temperature and salinity with depth, such as exists in the ocean, was neglected. Recently it has been recognized that calculations omitting the effects of systematic differences in density of only a few percent between the surface and the deepest bottom are often completely wrong.

Another recent theoretical development, stimulated by the practical needs of aerodynamics, is in the study of turbulence. The "frittering away" of large orderly motions by the development of successively smaller unstable eddies occurs in the ocean on an entirely different scale than in wind-tunnels, and is strongly influenced by stratification. Equally important in the ocean is another process that is somewhat the converse of this: the generation of the major ocean currents by steady winds. If a wind begins to blow over initially calm water, its first effect is to ripple the surface. Wavelets appear and grow. If the wind is strong and continued, the waves are accompanied by the transport of large masses of water. When the winds are steady in direction the

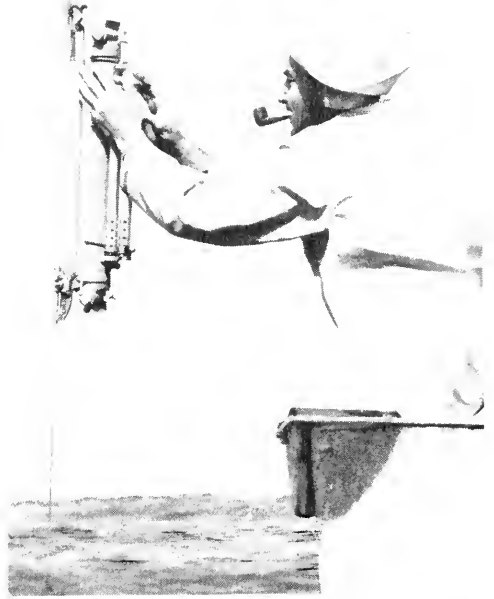
accompanying transport gives rise to the major ocean currents. Mathematically, the conversion of small waves into large currents is analogous to the conversion of large currents into small eddies. The general regime of the oceans must depend on a balance between the two processes.

Underwater acoustics has been the chief reason for the Navy's recent interest in physical oceanography. The permanent sound channel at mid-depths which is present over much of the ocean provides an effective means of acoustical transmission over great distances, as has been demonstrated in the air-sea rescue system known as SOFAR. Since the physical characteristics of the environment frequently become the limiting factor in underwater sound transmission, the Navy has encouraged basic studies in physical oceanography. As instrumentation in underwater acoustics has improved, sound in turn has become a primary means of exploring the ocean. It has been used for some time in determining the depth. Now it is being used effectively for exploring the geology of the ocean basins, and the use of sound holds great promise as a means of gaining quantitative information on the distribution of the larger animals in the sea. Acoustical techniques are also promising as a precise means of navigation.

Much interest in recent years has centered on the problem of predicting the height and period of sea, swell, and surf from the weather situations prevailing over the oceans. Knowledge of wave processes has increased to the point where meteorology, rather than oceanography, has become the bottleneck in the further refinement of wave forecasting. It is now evident that there may be certain advantages to the reverse procedure, to use observations on the period and height of swell to fill in details on the weather map in distant areas where the swell was generated. This is a particularly promising weather forecasting technique in the southern hemisphere where weather observations from over the ocean are widely spaced or entirely missing.

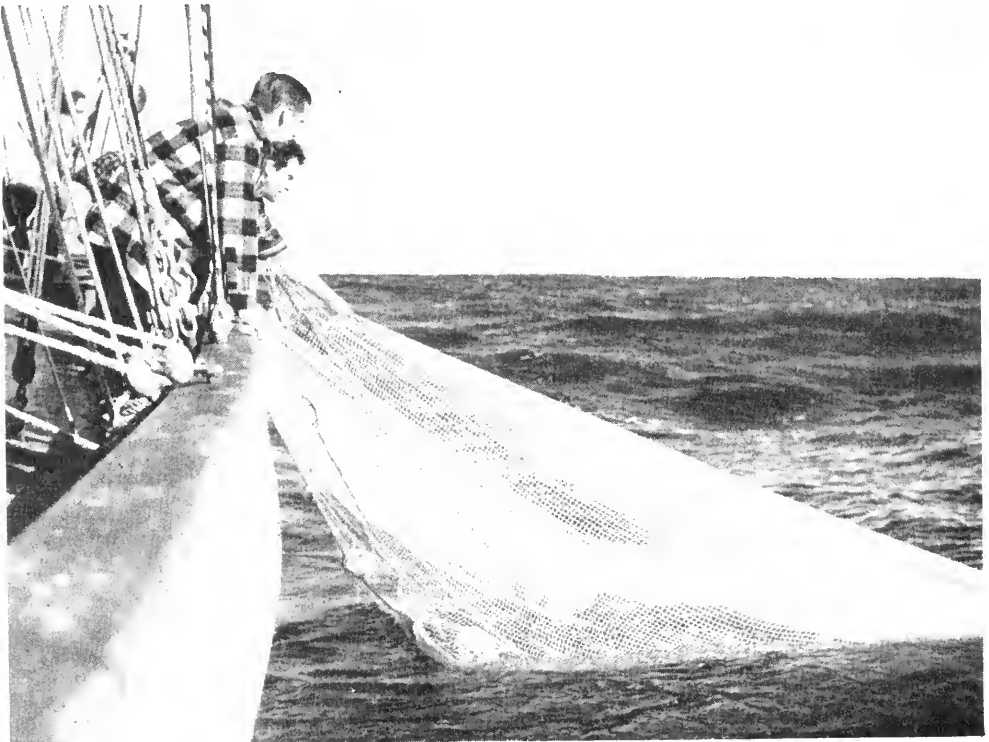


Using a chain dredge to obtain rock samples from the sides of submarine canyons.



Scripps Institution of Oceanography

Preparing to lower a sampling bottle to obtain data on the temperature and salinity at great depths.



Woods Hole Oceanographic Institution.

Hauling a trawl for exploratory fishing at mid-depth off the New England coast.



Scripps Institution of Oceanography

Measuring a manganese concretion brought up from a depth of three miles in the Gulf of Alaska.

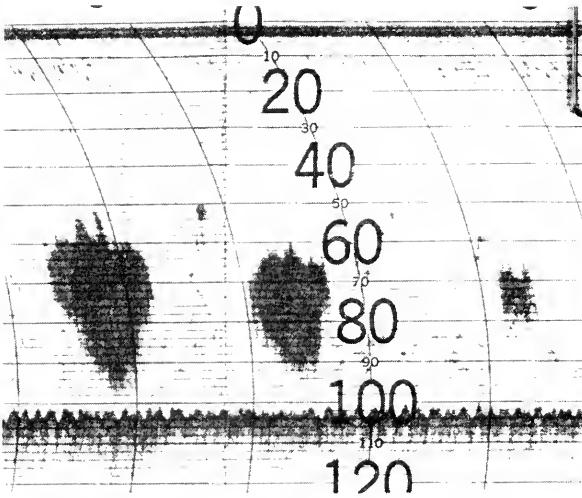
GEOLOGY AND GEOPHYSICS OF THE SEA FLOOR

The use of the recording echo-sounder and other instruments developed during the last decade has made it possible to conduct topographic surveys more rapidly and in greater detail than ever before. Although only a few isolated areas of the deep ocean have been surveyed in adequate detail, characteristic features of the sea floor have been revealed that had not even been suggested by earlier techniques.

Geophysical methods originally applied to the study of deep geologic strata under the land are yielding information about strata under the ocean. New techniques are also being developed to attack special geophysical problems of the sea floor. Results already obtained are so different in

fundamental respects from previous theory as to make it obvious that knowledge of the structure and history of the earth must depend largely on the accumulation of a body of data concerning the structure and history of the oceanic areas.

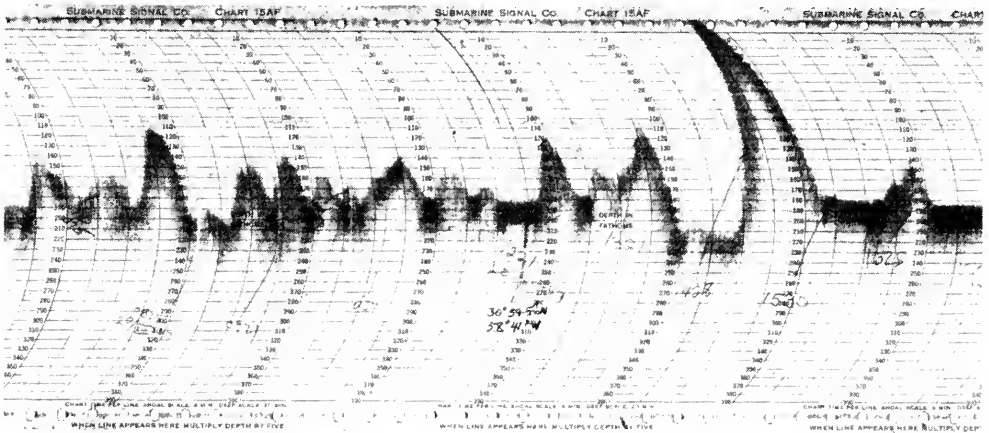
Recent improvements in coring devices make it possible to penetrate the bottom to depths of more than 100 feet. Sediments of the deep sea far from land have been deposited so slowly and continuously that the analysis of their fossil content and measurements of their radioactivity are resulting in a more detailed time-scale for the last million years of geologic history than can be obtained from terrestrial sediments. Oceanic sediments are likewise proving of interest to the astronomers. Certain elements concentrated in the sediments (i.e., nickel), may provide a clue to the history of the cosmos.



(Left) Record of sonic depth sounder showing echoes from schools of menhaden at depths of 60 to 80 feet.

(Below) Record of the depth of the sea showing roughness of the bottom over a course of 100 miles southeast from Bermuda. The large peak is due to a seamount rising six thousand feet from a depth of three miles.

Fish and Wildlife Service.



Woods Hole Oceanographic Institution.



Woods Hole Oceanographic Institution.

One thousand fathoms down—brittle stars and a sea spider photographed on the bottom.

THE CHEMISTRY OF OCEAN WATERS AND SEDIMENTS

Chemical studies in oceanography have been devoted largely to those components of sea water which are used by organisms in their life cycle: oxygen, carbon dioxide, nitrogen compounds, phosphate, silicates, etc. Although mixing of the oceans through the ages has brought the principal inorganic constituents to a monotonous uniformity, varied only by the addition or loss of small quantities of water, this is not true of those which enter substantially into the structure of living organisms. Phosphate and nitrate, on which fertility depends, are in general about fifty percent more abundant in the Pacific and Indian Oceans than in the Atlantic. In the Mediterranean, the quantities are much smaller. On a local scale the difference between each bank or embayment is even more marked. Although the causes of these differences are not well understood, they reflect the basic productivity just as surely as the fertility of the land is fixed by its climate, its geology, and the availability of crops suitable for each region.

Ninety percent of the nutrients in the sea are trapped in the greater depths where for the want of light they cannot be used by living plants. Only as vertical exchanges of water take place by turbulent processes and by upwelling are those substances brought near enough to the surface to permit their use. In exceptional places these processes are of such violence that great fertility results, but over most of the ocean the exchange is slow, so slow in fact that much of the available energy of the sun is wasted for lack of material to work upon in producing living matter. The high fertility of certain tropical waters can be traced to elements set free by the decomposition of organisms as far away as the Antarctic.

Since 1930 laboratory studies and surveys at sea of the distribution of oxygen and phosphate in the western Atlantic, the Caribbean, and the eastern north Pacific have substantiated the older concepts of the nutrient cycle. As a result, a theoretical ap-

proach toward understanding the water movements and biological processes which combine to produce or limit the productivity of given areas and the rate of circulation of nutrient materials between the surface and deep layers has already been made.

Recently it was demonstrated that several other elements often present in the soil in minute quantities may profoundly influence its fertility and the nutritive value of the plants produced. Likewise it has been shown that among the minor constituents of sea water, iron and manganese may be present in such small quantities as to limit the growth of plants.

Organic chemistry has scarcely been applied to sea water itself and only in a limited degree to marine sediments, although it is obviously of interest in connection with the formation of petroleum. It is known that sea water contains small residues of highly stable organic matter, that larger quantities are found wherever living organisms are undergoing decay, and that significant quantities occur in marine sediments.

THE BIOLOGY OF THE OCEANS

About the beginning of this century the scope of marine biology began to expand in many directions as attention shifted from description and phylogeny of organisms to the mechanisms of their life processes. Thus the many elements involved in the production and growth of organisms and in controlling their abundance, migrations, swarming, etc., became the dominant subjects of research.

The need for understanding fish fluctuations and allied problems has occasioned many studies on plankton, which directly or indirectly provides food for fish. Plankton fluctuates normally in abundance from season to season and also from year to year. The kinds of organisms present depend to some extent on the season, but one which is abundant one year may be scarce or absent the next or even for a series of years. In some areas, notably off Plymouth, England, the annual variations have been

correlated over a long period. Phosphate-rich water from the Atlantic is associated with one species of glass worm and a good herring year, but phosphate-poor water from the Channel with another species and failure of the herring fishery. As a result of these and other observations during the last twenty-five years, both in the United States and elsewhere, it is obvious that certain species are indicative of one water mass, others of another.

Thus, water movements affect the productivity of fishing banks. Eddies exist over Georges Bank, for example, in which young fish thrive and grow, but at times conditions occur which sweep the young larvae off the bank into deep water to the south, where they die. Following such a disaster, a poor haddock fishery is to be predicted in New England waters. Precise evidence that water movements may determine the productivity of an area could not be obtained until recently, however, as sufficient information of the character of the water movements involved was lacking.

Reactions of the organisms to environmental conditions, on the other hand, may in part control their distribution. Many zooplankton organisms migrate vertically in shallow waters—away from the surface as the light intensity increases each day, toward the surface at night. This provides a mechanism for transferring organisms from one body of water to another, perhaps to be dispersed in quite the opposite direction by counter-currents at various depths. More recently, a so-called “scattering layer” has been detected at considerable depths with echo-sounding gear. Like the layers found earlier in shallower water, this layer also moves toward the surface at night. Presumably it is due to planktonic organisms or other animals preying upon them.

Plankton studies are only one aspect of marine biology; fisheries biology has been studied chiefly in the areas where the fisheries are economically important. Fishery statistics, like plankton studies, show that the populations of many marine fishes fluctuate

from year to year. For some species these fluctuations depend on the success or failure of spawning. Variations in the ocean circulation may be the cause of this success or failure. Fluctuations may also arise from predator-prey relations, the predator checking the increase of the prey and then, in turn, declining in numbers for lack of food. Changes in abundance of useful fishes are often attributable to such mysterious cycles rather than to overfishing or to conservation measures. Studies must be made of food, enemies, and of the physical conditions under which each species lives to reach an understanding of these problems.

Marine organisms are subject to cataclysmic disasters and to severe epidemics whose nature and cause are unknown. The classic case is the tile fish, which was formerly abundant at the edge of the continental shelf off New York. In 1882 it was observed floating dead on the surface in countless millions. Subsequently, not one commercial catch of tile fish was landed until 1892. Since then it has slowly regained its former abundance and again forms the basis of a practical fishery. Twenty years ago the eel grass along the shores of the entire North Atlantic was blighted by an epidemic protozoan parasite. Within a year the whole shore-line ecology had changed, and only now are there signs of recovery. Recently a mass destruction of fish occurred on the west coast of Florida, in the so-called “red tide.” This was caused by a sudden “blooming” of poisonous microscopic plants. Epidemic diseases are also known to destroy oysters, clams, herring, and many other useful organisms.

The major part of the work in marine biology has been accounted for above, but several minor, although important, aspects are yet to be mentioned. Twenty years ago the role of bacteria in the sea was scarcely known, but today, largely through the leadership of Dr. Selman A. Waksman at Woods Hole and Dr. Claude Zobell at La Jolla, it fills a substantial textbook. Likewise, physiological investigations, often a

by-product of an oceanographic institution, have contributed substantially in recent years to interpretation of life conditions in the sea. These are so diversified and often so unrelated as to preclude a short discussion of recent accomplishments.

For several years it has been difficult to obtain the necessary financial support for marine biology, as the outcome of such investigations has been uncertain. In the past, data accumulated so rapidly that much of it was only superficially examined and reported upon. This was due to the slow and crude methods both at sea and in the

laboratory. New and more quantitative methods are necessary. New gear for use at sea while a vessel is underway is in the developmental stages, and new laboratory procedures to replace the older time-consuming methods of counting and identifying the various species are being tested. With the new understanding of water movements, it will be possible to formulate the problems more exactly and thus obviate much unnecessary collecting of data. In short, when funds become available, marine biology should make greater strides than have been possible in the last fifty years.

APPLICATIONS OF OCEANOGRAPHY IN PEACE AND WAR

MAN'S USE of the ocean has greatly increased in recent years, and it may be expected to increase in the years to come as we learn more and as we improve our technology. The ocean is an immense reservoir of natural resources: minerals, power, fuel, water, food, and other organic products. In addition its great size and vigorous metabolism make it a useful receptacle for the disposal of the waste products of civilization. Finally, it affords a medium for transportation and a means of national defense.

THE OCEAN AS A SOURCE OF POWER

In areas where the tidal range is large, as in Passamaquoddy Bay, utilization of the rise and fall of the tide for hydro-electric power is practical from an engineering point of view. The enormous energy of ocean waves can be exploited for power purposes in certain areas, particularly along exposed coasts on the western side of continents. It may eventually be possible to exploit the difference in temperature between surface and deep waters in low latitudes through the use of low pressure steam engines. The last two potential sources of power are not of major engineering interest at present because power can be obtained more cheaply from coal and from the hydroelectric development of rivers.

The amount of uranium in the oceans could be made to furnish power at the present world rate of consumption for nearly a million years, but the concentration of uranium per unit volume of water is so low that it might take more power to extract the uranium from sea water than could be obtained from it.

THE OCEAN AS A SOURCE OF CHEMICALS

Although it is not now economically feasible to utilize many important minerals present in great dilution in sea water, it is to be presumed that when high grade de-

posits on land are worked out methods of extraction from the sea will be developed. The oceans are at present the principal source of bromine and magnesium. In fact, if the latter were to replace iron the supply would still be sufficient for over ten million years. We may anticipate some such substitution if the standard of living throughout the world becomes equal to that of the United States today, because the increased consumption of iron would exhaust present supplies in about seventy-five years.

If, on the other hand, iron and steel continue as the basic metals of our industrial civilization, the extensive manganese deposits of the deep sea floor may eventually be utilized. This substance, essential in steel working, is present in minute traces in sea water, but occurs as crusts, often several inches thick, of manganese dioxide over the rocky summits of submarine mountains. On one such sea mount in the central Pacific, twenty miles long and ten miles wide, it is estimated that there are fifty million tons of manganese, ten times the present annual world production.

Sodium chloride, iodine, potassium, phosphate and vanadium are now obtained largely from deposits laid down beneath the sea in past geologic ages. A considerable portion, however, of the world requirements for sodium chloride and iodine now come directly from the ocean. Some substances present in the sea in relatively small amounts, such as gold, radium, and iron, will probably continue to be obtained chiefly from rocks of non-marine origin. Contrary to popular belief, the quantity of gold in sea water is not sufficient to make everyone a millionaire. If it were all extracted and divided equally, each man, woman, and child would receive an amount worth about four thousand dollars.

Although the plant resources of the ocean are only exploited on a small scale, a very

considerable increase in yield is practicable. The total production of seaweed could probably be increased to at least twenty million tons annually, an amount equal to the present world fish catch. New uses in the textile, paper, and food industries and in agriculture are constantly being found for the organic components of seaweed. One promising future development is the use of these substances as food for yeasts and other protein-making micro-organisms.

The water itself in the ocean constitutes a resource of actual and potential importance. Sea water is now commonly used for cooling purposes in industrial plants near the shore. In many semi-arid regions the water supply from ground and river waters is becoming insufficient for human requirements. Serious study is being given to the possibility of obtaining additional supplies of fresh water directly from the ocean by distillation, as has been done in certain oil communities on the West coast of South America, and by other means.

FISHERIES PROBLEMS

Organic products from the ocean today constitute the principal marine resource utilized by man. The annual yield of the world's fisheries is some 20 million tons, corresponding to about 1 million tons of protein, or only about one-fiftieth of the total protein consumption. Yet more than half the world's population has a diet which is seriously deficient in protein. This deficiency will become more serious if the population continues to increase at the present rate. Therefore all possible means must be sought to increase the yield of the sea fisheries, particularly of the deep sea, and to educate people to eat more fish.

Fishermen are conservative and continue to use the same techniques year after year, chiefly because the economics of the industry does not encourage search for better fishing grounds, new fisheries, or improved methods of catching fish. Nevertheless, new resources have been developed in recent years even in such a thoroughly fished region as off the New England coast, and with little change in boats or gear.

Within ten years, the fishery for rose fish grew from negligible proportions to yield in 1941 some 145 million pounds, and is now the second most important fishery of the coast.

Within the past few years, it has been found that the fish populations beyond the continental shelves are far greater than previously supposed. Many of these fish are small and do not school, so that radically new techniques of location, capture, processing, and marketing must be developed before this resource can be exploited. The development of underwater acoustics affords a means for locating fish. With further improvements in instrumentation, acoustic techniques should make it possible to explore the depths of the sea for all sorts of organisms and to estimate their size and number. Already the detection by acoustic means of a deep "scattering layer," presumably a dense population of planktonic animals or fish feeding on them, has suggested that at intermediate depths fish are as abundant as at the surface or on the bottom, where most commercial fishing now takes place. New nets for fishing at mid-depths must be devised, however, to explore this potential fishery. Acoustic studies likewise have shown that many fish, crustacea, and whales all make noises. Fish have, in their lateral line organs, receptors attuned to low frequency vibrations, which presumably serve some purpose in their activities. This suggests the possibility of using sound to lure fishes into traps or to herd them into nets.

Comparatively little effort has been directed toward the aspects of fisheries research just described; rather the goal of most fisheries work has been to predict the quantity and quality of fish that can be caught under specified circumstances. The work is so diversified that it covers all phases of oceanography. Fishery biologists must concern themselves on the one hand with marine environments, i.e., with currents, nutrients, winds, temperatures, etc., and on the other, with the economics and analysis of catch statistics, as well as with interrelated biological problems. Natural

mortality rates throughout the life of the fish, as well as food, predators and competitors, diseases, migrations, etc., are all subjects for study. The size of fish stocks are known to be influenced by many things: by fishing, by fluctuations in the survival of fish eggs and larvae resulting from changes in the environmental factors, by devastating epidemics, and perhaps by cyclic changes inherent in fish populations. These problems are analogous to those occurring among populations of mammals and remain beyond our understanding.

Heretofore most fishery research programs were attempted on too small a scale. This was due to a lack of appreciation of the complexity and magnitude of fishery problems, so that insufficient funds were assigned to many projects. Recently, however, a number of laboratories along the coasts have combined in cooperative efforts, as for example in the California sardine program, the Atlantic clam investigations, and the Gulf of Mexico survey.

APPLICATIONS OF OCEANOGRAPHY TO METEOROLOGY

The influence of the ocean upon the climates of the coastal regions has long been recognized and, in a general way, it is known that the configuration of the oceans and the major land masses exercises a profound control upon the character of the atmospheric circulation. Differences in weather between the northern and southern hemispheres, for example, depend primarily on the different proportions of land and sea in the two hemispheres. Short term changes in weather occurring within a few days evidently depend on instabilities within the atmosphere itself, but in order to extend weather forecasts over a longer period it is believed that it will be necessary to take into account changes in ocean circulation, and in the temperature and salinity of the surface waters. Thus a rational basis for long-range weather forecasting may depend to a large extent upon an increase in our knowledge of the fluctuations of oceanic conditions.

Oceanographic research has already resulted in one new method for determining and predicting weather conditions over the ocean. Storms generate waves of long period and of very low amplitude which travel at speeds of several hundred miles per hour. By recording such waves as they arrive at one or more shore stations, it is possible to locate and track the storm over areas of the ocean in remote parts of the world.

One of the most interesting and significant problems of modern meteorology is that of the overall vigor of the atmospheric circulation and its fluctuation with time. It is difficult to integrate ordinary weather data in order to compute these fluctuations because of the inadequate and irregular distribution of weather observing stations, but they can be determined from other types of geophysical observations. For example, the short period, seasonal fluctuations in the speed of the earth's rotation probably reflect, in large part, changes in the intensity of upper atmospheric winds. The speed of the earth's rotation is also markedly influenced by changes in sea level; it is believed that these in turn depend, in a complex way, on atmospheric fluctuations. Thus in order to use fluctuations in the speed of the earth's rotation as an index of the overall atmospheric circulation, it is necessary that we know how and by what processes the sea level is affected by changes in the atmosphere.

FINDING AND PRODUCING PETROLEUM

Petroleum is found associated with marine sedimentary rocks. Indeed it is now believed that nearly half of the oil remaining in the earth occurs in the sedimentary rocks still beneath the oceans. Several major oil companies are attempting to find and produce this oil and have enlisted the help of oceanographers to predict wave conditions which interfere with operations. Oceanographic knowledge is also needed to extrapolate from the point of measurement the thickness and character of the recent sediments of mud and sand after these have been determined at any particular

locality by jetting down to the underlying rocks.

Of more basic importance to the oil industry is an understanding of the mechanism of formation and accumulation of petroleum in marine sedimentary rocks. Almost every type of environment in which oil-bearing sedimentary rocks were laid down in past geologic ages now exists beneath the ocean. By studying detailed characteristics of the sediments being deposited in these environments the submarine geologist can greatly aid in the search for new oil pools. Much oil, for example, occurs in ancient coral or shell reefs. By observing the ways in which reefs of the present day vary in character laterally and vertically it becomes easier to predict from well logs and geophysical data the character of the rocks concealed far below the surface and the directions in which drilling should be extended. In addition, much oil occurs in "traps" formed by impervious sediments on the sea floor as controlled by depth of water, distance from shore, and waves and currents.

BEACH EROSION AND CONTROL

It is estimated that a strip of land averaging one foot in width over the entire 52,000 miles of shore line of the United States, or approximately 6,400 acres or 10 square miles, is annually lost by beach erosion. In some regions, such as in the Chesapeake Bay area, the unprotected shores of developed and agricultural lands are cut back as much as fifteen feet or more per year. By conservative estimates, shore erosion and control costs the people of the United States about 100 million dollars annually. The State of New Jersey alone has spent a million dollars a year for the past twenty years to protect its beaches. This is a small part of the total value of the shore front property. At Atlantic City, which is largely dependent on the maintenance of some 10,000 feet of beach, the shore front property is valued at about 200 million dollars.

There are three major types of shore control problems. The first concerns stabilization and rehabilitation of developed

beach areas by building protective structures to resist the attack of the sea, and to regain at least a part of the shore already lost. In many areas, highways, homes, hotels and business establishments have been located immediately adjacent to the beach with little allowance for encroachment by the sea. With the passage of time normal beach erosion occurs and the structures are endangered or damaged.

Another type of problem results from dredging deep navigation channels into rivers or harbors. A natural inlet channel has a depth in equilibrium with the rate of material transport along shore and with the tidal flow characteristics of the inlet. This equilibrium is destroyed by deepening the channel and the natural forces tend to re-establish the equilibrium by filling the dredged area. If jetties are built to prevent refilling of the dredged channel the natural movement of material along shore will be stopped and the down-drift beaches will rapidly become eroded.

A third type of problem arises when breakwaters are built to construct or improve harbors which impede the natural long-shore movement of beach materials. This often results in starvation of the down-drift shore and in excessive accretion of materials on the up-drift side of the harbor mouth. The latter may shoal the harbor mouth itself unless provision is made to maintain or re-establish the movement of materials around the harbor entrance.

To solve shore control problems one must know the sources and rates of supply and removal of sedimentary materials and understand the processes which cause erosion and transportation. Materials will be brought into and out of the area by long-shore drift and by motion between the beach and the adjacent sea bottom. Rivers and streams may carry material into the area and the wave erosion of sea cliffs back of the beach also furnishes material to the beach. Wind action often removes materials to form barren dune areas inland from the shore.

Waves are the principal source of energy changing the shoreline. Waves produce a

destructive impact on the shore and on man-made structures, and they transport beach sands, pebbles, and boulders. The piling up of water along the shore by the waves causes longshore currents which also transport beach materials. Waves which affect the shore line originate in part from local storms and in part from storms many thousands of miles away. For example, destructive erosion in Southern California is most commonly caused during the fall months by long swells generated by storm winds in the southern hemisphere. This swell is hardly perceptible in deep water off shore, but as the waves come into shallow water and approach the beach the distance between crests is greatly diminished, and the waves peak up until at the point of breaking they may be more than twenty feet high. The height, period and direction of waves coming into the beach zone is of critical importance in determining longshore currents, and the character of erosion and transportation processes. The height and direction will be affected by the bottom topography offshore, while the period will depend primarily on the meteorological conditions and the location of the generating area. The off-shore topography, particularly the presence of submarine canyons or other irregularities, will also determine the rate of loss of sedimentary material from the shore. An understanding of the many processes involved in the interaction of waves and bottom materials should yield practical benefits in protecting and improving shores and shore line structures.

In addition to waves several other oceanic processes play a major role in shore line protection problems. Where the shore is low and flat serious inundations may occur because of piling up of water by storm winds blowing on shore. Such inundations may also be brought about by tsunamis (seismic sea waves) from submarine earthquakes. The height and intensity of a tsunami varies widely from one area to another along shore depending on the bottom topography and the configuration of the ocean basin. Little is known of the

probable height and intensity at any point in the sea of a tsunami originating from an earthquake of given magnitude. The solution of this problem will require an increase in our understanding of the hydrodynamics of a compressible, viscous, stratified fluid such as the ocean.

PROBLEMS OF OVERSEAS TRANSPORT

With the development of large, fast, engine-powered ships and of modern communication, new problems concerning the ocean have arisen and old ones have diminished in importance. Yet the sailor still needs to know as precisely as possible where he is and how his course and speed are being altered by currents, winds, and waves. He must avoid collision on the high seas and stranding on the shoals and rocks near shore. His ship must be stout enough to withstand the violent action of the waves and yet as lightly constructed as possible so as to eliminate useless dead weight and volume.

Until recently there has been inadequate knowledge of the characteristics of ocean waves and their effects on ships. As a result, ships have been built to withstand very high waves with a large factor of safety. The greatly increased knowledge of the shapes and motion of waves of the last few years should result in radical improvements in ship design.

Sailors, ship-owners and government have long recognized the need for knowledge of tides, currents and bottom depths in near-shore areas. More recently the development of echo sounding and of accurate means of surveying far from shore have become possible. Accurate charts of the deep ocean basins would be a considerable aid to navigation.

The sinking of the *Titanic* in 1912 emphasized the danger from icebergs in the North Atlantic. Shortly thereafter the International Ice Patrol was organized to give warning of the presence and movement of icebergs. The tracks followed by the bergs from their origin in the fjords of West Greenland are controlled by ocean currents in Baffin Bay, Davis Strait, and the West-

ern North Atlantic, as shown by comparison of currents with the observed tracks of icebergs. The United States Coast Guard, which operates the International Ice Patrol, now computes currents from detailed temperature and salinity observations each season to predict the probable number and location of dangerous icebergs in the Western North Atlantic.

In the days of sailing ships, knowledge of the direction and speed of major ocean currents far from shore was useful in shortening the time required to sail from one port to another. With the development of faster vessels, less advantage was taken of currents because they represented only a small fraction of the speed of the ship. Recently, however, it has been shown that in certain areas major ocean currents, such as the Gulf Stream, are much narrower than had previously been supposed and flow at greater velocities, up to seven knots. If such high speed jets in the ocean can be readily located, considerable advantage is to be had even for large, fast ships.

The development of air travel over the ocean has increased the necessity for detailed current information on the high seas in order to locate survivors from trans-oceanic planes forced to ditch at sea. Methods for locating survivors on life rafts at sea developed during the last war were based on the best estimates then available of the surface currents and the effects of winds on these currents and on the rafts. The location of survivors on life rafts is facilitated if a reliable means of communication between survivors and searching parties is available. Underwater sound (SOFAR), trapped in a water layer or "sound channel" and transmitted for great distances, may be used for this purpose. Stations have been established in the Pacific to locate by triangulation the source of sound produced in this "channel" by the detonation of bombs dropped by survivors.

In the past the icy wastes of the Arctic Sea have been avoided by all but a few explorers, but in future it can be expected that this area will be more and more trav-

eled by ships and aircraft. Knowledge of the movement, strength, thickness, and distribution of sea ice will be essential for navigation in this area.

MILITARY OCEANOGRAPHY

The great expansion of oceanography during the past ten years, amounting to a ten-fold increase in the number of persons employed and the amount of money expended, can be traced directly to recognition of the importance of oceanographic information for military problems. More than half of the funds being expended for oceanographic investigations at the present time come from the Department of Defense.

Oceanography has military applications of four types: (a) in the design and specifications of new equipment to take maximum advantage of the properties of the oceans; (b) in testing new equipment to meet requirements in operation at sea; (c) in the tactical use of equipment to take maximum advantage of oceanic conditions either as observed or forecast; and (d) in strategic planning where knowledge of average oceanic conditions can be used in selecting the time and location of military operations, the type of equipment to be used, and the most effective disposition of men and materiel.

During World War II, oceanographic research and information found effective application in amphibious and undersea warfare. In amphibious warfare the success of beach landings depends on accurate knowledge of conditions in the surf and shore zone. The most important of these is the bottom topography immediately offshore, which may change rapidly depending upon changes in wave height and direction. If landing craft become stranded before they reach the beach, the landing troops may be subjected to a withering fire in wading ashore and may be unable to cross an intervening deeper zone. Just such a situation existed at Tarawa, and the losses incurred in that operation stimulated the effort to find methods of determining bottom depths in shallow water. Second in importance to the bottom topography are

surf and current conditions within the breaker zone. Casualties to landing craft increase rapidly as the breaker height increases beyond a relatively low value. Also, with swift longshore currents, landing boats tend to broach on the beach and are unable to retract after landing.

The unloading of cargo into lighters of various types is also impeded by high waves. This was graphically shown in the Normandy operation, where the rate of cargo transfer from the ships offshore to the beach was decreased by more than 50 percent during periods of high waves. Thus accurate prediction of breaker height, direction of approach, and other surf characteristics is valuable in guiding landing operations and may be useful in other ways. For example, it is sometimes possible to gain the advantage of surprise by utilizing marginal conditions in which landings can actually be made, but where the defending forces have a sense of false security because they believe conditions impossible for landings. A method for predicting surf conditions was developed during the war and taught to meteorologists who were later assigned to various operating staffs. These meteorologists were able not only to predict surf conditions from weather data, but also to select areas along the beaches in which surf heights would be minimal from knowledge of bottom topography and the principles of wave refraction. In the invasion of Sicily the defending commander believed that a landing was impossible because of a storm during the night. The aerologist on the American naval commander's staff, however, predicted that the waves would drop at dawn and that a landing could be made.

By far the largest number of oceanographers were engaged during the war in research and development for undersea warfare. The principal problem was, and remains, that of detection of submerged submarines without being themselves detected. The *raison d'être* for submarines is, of course, the relatively poor penetration of

light and electromagnetic radiation through the ocean. On the other hand, sound is transmitted better through the ocean than through the air. Undersea warfare is thus a deadly game of blind man's buff in which the winning side is most likely to be that with the most acute hearing. Although underwater sound is the chief means of communication with submerged submarines, its effectiveness varies widely with varying conditions in the ocean. Vertical temperature gradients in the upper layers refract the sound so that it is transmitted for only a few hundred yards in some cases, or for many thousands of yards in others. Inhomogeneities in the water scatter and distort sound. In deep water, these "scatterers" are probably very largely plankton organisms and their predators, concentrated at intermediate depths of about 200 meters. In shallow water the bottom acts as a reflecting surface which at times aids in sound transmission but at other times causes reverberations that prevent transmission of a recognizable signal. The ultimate range to which sound can be transmitted depends on the background noise in the sea. In addition to noises made by the ships themselves, there are noises due to breaking waves at the surface, to the collapse of bubbles, and, in shallow water areas, to noisy organisms. Underwater sound is absorbed in sea water much more rapidly than in pure water. This has been shown to be due to the presence of magnesium sulfate in the water. Thus every aspect of oceanography—physical, chemical, biological and geological—has direct application to military problems of underwater sound.

Such are the problems that have brought about generous support of the oceanographic laboratories by several government agencies. No doubt many other practical applications will develop. Although some of these are of considerable scientific interest, under the present system of government subsidy in oceanography some important scientific problems tend to be neglected.

CURRENT PROBLEMS IN DEVELOPING OCEANOGRAPHY IN THE UNITED STATES

CHARACTERISTICS OF MODERN OCEANOGRAPHIC FACILITIES

THE ORIGINAL facilities for oceanographic research both in this country and abroad were chiefly developed by marine biologists. The work followed two major patterns. Research on the high seas was conducted by large-scale expeditions often lasting several years, such as those of the *Challenger*, *Albatross*, *Meteor*, *Carnegie*, *Dana*, and *Discovery*. The relatively simple equipment consisted chiefly of devices for collecting samples of sea water, sediments and other bottom material, and specimens of marine organisms. The materials collected were brought back to shore and distributed among various experts throughout the world for description or analysis.

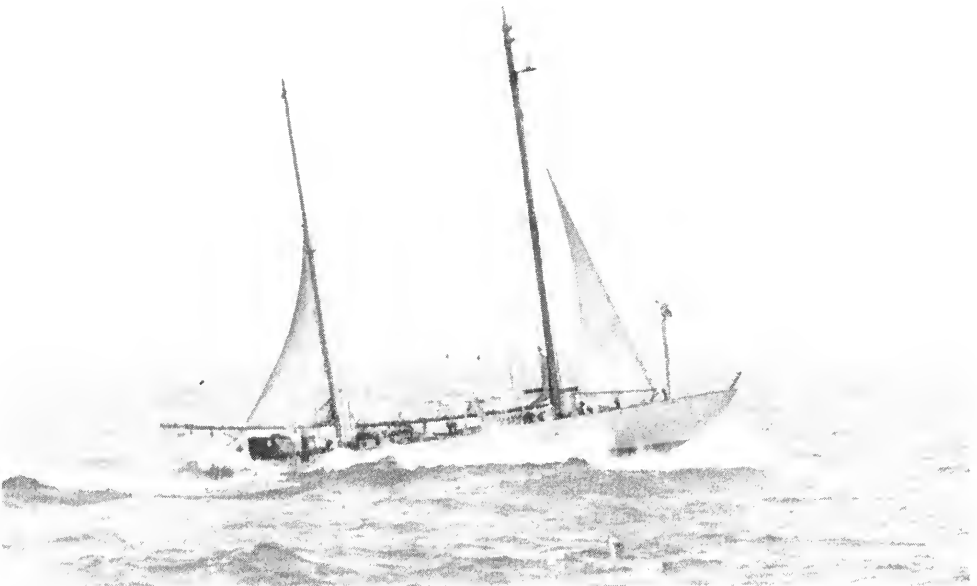
At the same time, many small marine stations were established to which university people could go for the summer or for vacation periods to do research. The scope of the work was mainly determined by the small size and short cruising radius of the laboratory vessels. In the United States these laboratories were supported principally from private funds and on a modest scale as compared with those in Scandinavia, Germany, England, and Japan, where government support was available.

As a result of developments in the basic sciences and in techniques of instrumentation, especially in the last ten years, oceanographic research has changed in character and the required facilities have increased in complexity and cost. In this country it now usually involves a concentrated and coordinated attack on specific problems, in which the field work is confined to limited areas revisited at frequent intervals. For example, a cooperative program of the United States Fish and Wildlife Service, the California Division of Fish and Game, and the Scripps Institution of Oceanography

to determine the relationships of hydrographic conditions to the productivity of the California sardine fishery, involves monthly surveys (by four ships, each cruising about 2500 miles per month) of the waters off the West coast of the United States and Lower California. As many as six ships have been used simultaneously in a study (by the Woods Hole Oceanographic Institution and the Hydrographic Office, with the cooperation of the Fish and Wildlife Service and the Naval Research Establishment of Canada) of the detailed structure of the Gulf Stream and its periodic fluctuations in position and strength.

Such investigations require laboratory experimentation and model studies and the development of analytical methods, as well as new instruments and techniques for work at sea. For much of the latter, sturdy vessels are needed, capable of operating in any weather and of handling gear weighing two or three tons suspended from heavy wire ropes often several miles long. Extensive shop facilities are essential for the development and construction of both laboratory and field equipment. In these developments there must be ready access to ship facilities for testing at every stage.

The requisites of modern oceanographic investigations are thus comparable in many ways to those of astronomy and present similar organizational problems. Important work can be accomplished by small groups of scientists with relatively inexpensive facilities, but for many of the major problems the facilities needed are extensive and complex. Consequently large seaside laboratories with funds adequate to operate ocean-going vessels are indispensable. The operation of such large institutions involves logistic planning on a scale unknown in most laboratory sciences and rarely encountered even in field work on land.

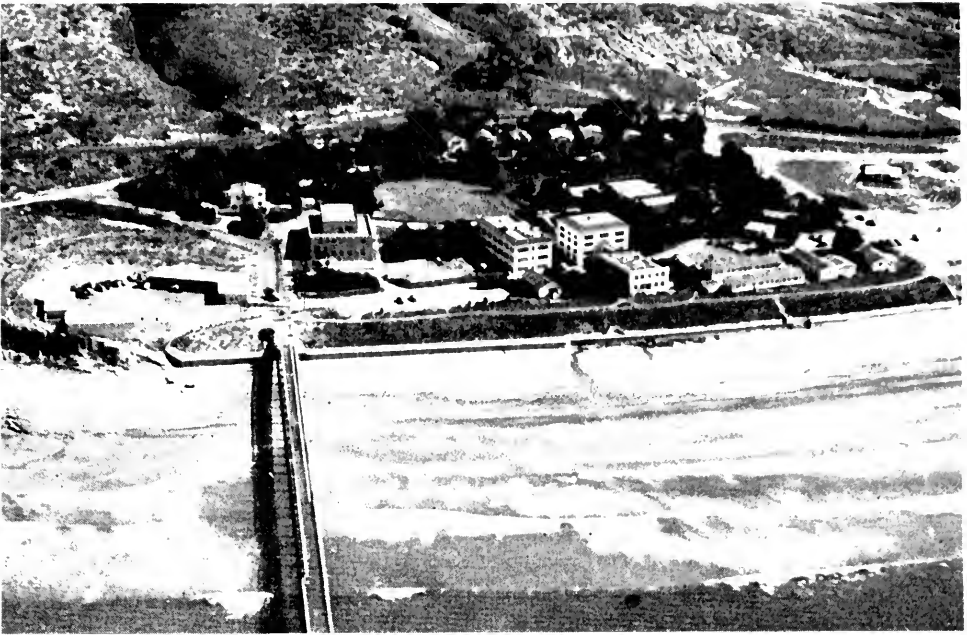


Naval Research Establishment, Halifax, N. S.

The *Atlantis*, research vessel of the Woods Hole Oceanographic Institution, at work in the Gulf Stream.



The Woods Hole Oceanographic Institution.

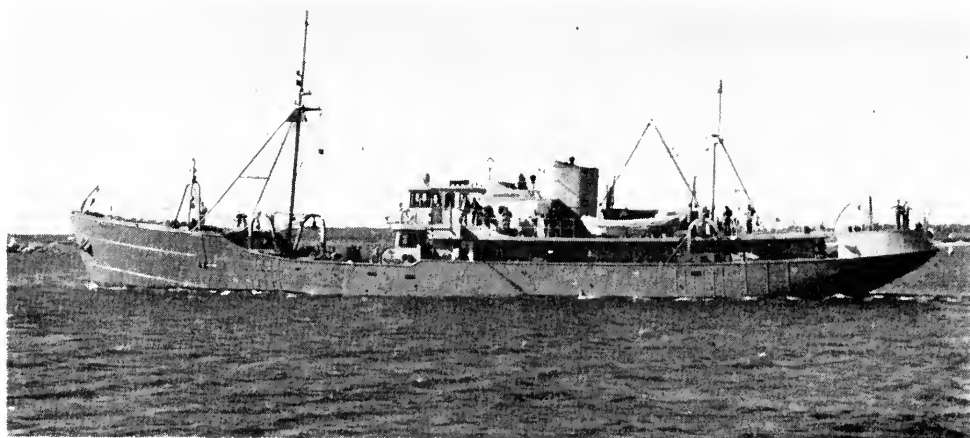


The Scripps Institution of Oceanography, University of California, at La Jolla, California.



Scripps Institution of Oceanography

The *Crest*, one of the ocean-going research vessels of the Scripps Institution of Oceanography, University of California.



Woods Hole Oceanographic Institution.

The Albatross III, one of the vessels of the Fish and Wildlife Service, U. S. Department of the Interior.

Although one of the responsibilities is to carry on unbroken series of routine observations, the major responsibility should always be to use the facilities creatively in advancing our understanding of the oceans. It is vital to preserve the flexibility of method and freedom of choice of objectives which have proved so essential for the healthy development of all the sciences. One means of insuring optimum creative use of the facilities of the oceanographic institutions is to provide for a flow of visiting scientists from universities and abroad.

SHIPS

Deprived of vessels with adequate laboratory arrangements, oceanography would soon cease to produce new means of attacking problems. This is the weak link in the chain on which the effective use of the available government appropriations for applied oceanography depends. Oceanographic ships should be regarded as vehicles on which investigators and their instruments are carried to sea. Their operation must be directed by men who understand and can coordinate the varying requirements of the scientists, and the crews must learn the special needs of the scientific work on which the success of a voyage depends.

Because it is inefficient to use a large

ship for work that a small one can do, there is need for a variety of oceanographic vessels. These range from motor launches to ships capable of crossing the ocean and remaining at sea for long periods. Larger ships are equipped with special winches for lowering heavy equipment to the bottom in the deepest water. They have laboratories and modern electronic equipment for position finding and for exploring the ocean depths. The operating budget of such vessels ranges from \$50,000 to more than \$150,000 per year.

It is often suggested that oceanographers make more frequent use of government survey and fisheries vessels, but most government vessels are inadequately equipped for oceanographic work. Some have winches that are suitable for shallow water investigations but not for deep water. Laboratory accommodations are poor or entirely lacking. However, the chief trouble is that the vessel usually has a primary mission other than oceanography. Hence the route is prescribed by other requirements, and relatively few hours of a voyage often lasting several weeks or months can be devoted to such secondary work. Occasionally security problems are involved, especially on naval ships. Some naval and other government agencies, to be sure, have

vessels primarily employed in oceanographic surveying. Because of their expensive operation, inflexible operating plans, crowded work load, and difficulty in arranging for temporary installations, these are not often suitable for testing new methods or techniques.

Although a large amount of new construction is not required immediately, the time will soon come when present vessels, most of which were not designed for oceanographic work, will need to be superseded by economical diesel-propelled craft with the laboratory and deck space required by modern scientific equipment, and capable of remaining at sea for protracted periods. Funds are also needed to allow greater use of existing bottoms for basic research. It is particularly desirable to obtain support for a new cycle of exploring expeditions, using the new techniques and equipment developed in recent years to survey the wide and virtually unknown expanses of the high seas.

SHORE FACILITIES

At only one of the three major oceanographic institutions are the shore facilities reasonably adequate for present needs. The physical plant of the Oceanographic Laboratories of the University of Washington is not yet occupied to capacity. At the Scripps Institution of Oceanography, temporary wooden structures both at La Jolla and on Point Loma have been provided by the Navy. Little space is available for visitors, however, and such essential facilities as running sea water and many of the more expensive types of laboratory equipment are not available at Point Loma. At the Woods Hole Oceanographic Institution the facilities are over-taxed even for the permanent staff, and working space for visitors is wholly inadequate.

MANPOWER AND EDUCATION

The problems of manpower and education in oceanography arise from the small size of the group concerned, which is limited not by the scope or importance of phenomena to be studied but by the expense

of oceanographic work. The costs prohibit universities from developing skilled workers after the usual pattern. Some special solution of the problem of education is required.

During and since the war, opportunities for oceanographic research have increased more rapidly than has the number of trained oceanographers. Positions open to students of oceanography are for the most part in government laboratories or in university departments devoted to some established related field. Once these positions are filled, the demand for trained men is likely to decline so that perhaps ten good recruits per year will suffice for all the openings now envisioned. How to attract men of high capacity into such a field, and how best to provide for their training, is a perplexing question. It will probably not be advisable to increase greatly the number of departments of oceanography in the universities, but it is desirable that more men trained in the subject find places in other appropriate departments and thus stimulate undergraduate students to enter the field.

The oceanographic laboratories must always retain a central position in training oceanographers since they alone can provide first hand experience in work at sea. Young oceanographers should serve an apprenticeship at one of these as graduate students or through postgraduate employment. Relatively few, however, can hope for permanent employment since the senior positions of the staff must remain limited in number.

A more adequate and varied senior staff at each of the oceanographic laboratories is urgently needed. At present there are perhaps twenty-five men in the three major institutions who serve with tenure and devote their major effort to the subject. Accordingly, since oceanography is based on at least four of the recognized fields of science—physics, chemistry, biology, and geology—no one institution has a well balanced staff. For a better balance, doubling the number of senior positions appears to be a minimal requirement.

Oceanography is the integrated extension of many fields of science beyond the beach line and therefore it does not fit into the usual university department. One university may have a notable professor of marine biology, another a man interested in the chemistry or geology of the sea; thus Harvard, Yale, Columbia, Washington, and several others have professorships in one or another of the oceanographic sciences, or professors whose field of research is properly classed as oceanography. The existing opportunities for research and instruction should not be underestimated, since they have provided the training for our present leaders in oceanography. However, they do not cover the subject as a whole in a systematic way. Only one university offers a well-established and integrated course of study leading to advanced degrees in oceanography. This is the University of California, through its Department of Oceanography at the Scripps Institution. In 1940-1941 this department had seven regularly enrolled graduate students, in 1948-49 it had fifty. It has thus become the principal agency for training oceanographers in this country. Within the last few years the University of Miami has established a Department of Marine Sciences with courses leading to a master's degree. More recently Texas Agricultural and Mechanical College has announced the formation of a Department of Oceanography with a program of instruction. Such a development is also contemplated at the University of Washington where up to the present training in the Oceanographic Laboratories has been recognized by degrees granted in one or another of the departments devoted to a basic science.

It still remains a question, however, whether the greatest strides in oceanography will be made by men trained by specialized courses in oceanography or by those recruited from other disciplines who elect some aspect of oceanography as their special field of study. Frequently meteorologists, physicists, and others have found that the oceans provide a good medium for

solving a particular problem. Subsequently, they may become interested in other investigations and remain in the field. They bring with them new methods and new ideas adapted for work at sea. Men with originality will always infuse new concepts and thus advance oceanography. Such men should be encouraged by providing them with every facility to work at sea from the oceanographic institutions in addition to any formal education in other subjects elsewhere.

Oceanography can now claim as much cultural value in education as astronomy or geology. Recent appointments of oceanographers, as at Brown and Cornell, give evidence that this opportunity is being recognized. An elective undergraduate course in oceanography might well be established on a larger number of campuses, or courses in the basic sciences might be expanded to give students an opportunity to learn as much about the physics, geology, and biology of the oceans as they do about the land. The interrelated sciences of the sea form an ideal framework for demonstrating the unity in methods and the diversity in content which characterize modern science.

The solution to the problem of educating oceanographers which is developing and should be encouraged is less provincial than the usual academic pattern of graduate study. Although few universities can afford a faculty in oceanography or operate a research vessel, the combined resources of the oceanographic laboratories and the universities can provide such training and experience. Thus a few selected students should be given an opportunity to find their training where best they may beyond the limits of a single campus. The cordial relations which exist between the several institutions now concerned and the varied cooperative arrangements in effect give evidence that this is a practical solution.

In short, the requirements for providing an adequate supply of research workers in oceanography are these:

1. The presentation of oceanography as

a unified subject at the undergraduate level in a larger number of colleges.

2. The establishment of a few posts for men concerned with oceanography in a number of universities, but attached to any appropriate existing department.

3. The development of a more balanced staff to guide research at each of the major oceanographic laboratories, through an increase of personnel with tenure.

4. The provision of graduate and post-doctoral fellowships to enable outstanding students to take advantage of available educational opportunities in this country and abroad.

THE FINANCIAL PROBLEM

Prior to World War II the support available for oceanography outside the Government services was roughly \$300,000 per year. This maintained the three larger laboratories and the oceanographic work at a few small biological stations. It also operated three research vessels, of which only one was capable of extended offshore cruising. Including graduate students and summer investigators a total of perhaps 120 people were able to take part in the advancement of the marine sciences. Full-time researchers, including those holding university professorships, did not total more than twenty. Practically no support was received from Federal or State funds except through the regular budgets of the State universities.

Since the war, substantial increase in the assured resources of the three major oceanographic laboratories has occurred only at the Scripps Institution, where the budget has been increased by about \$180,000 per year. Thus the sum assured for the purposes of these laboratories has only increased from a pre-war level of \$300,000 to \$480,000 per year, but because of increased costs, especially in operating ships, at least \$750,000 per year would be required to maintain the pre-war level of activity. The discrepancy between this sum and that now available, amounting to \$270,000 per year, is one cause of the

difficulties under which these laboratories now operate.

Owing to the current interest in the military applications of oceanography and a growing concern for fisheries, relatively large sums of money have become available for restricted purposes from Federal and State funds. Fisheries investigations are being supported by many of the states in the Atlantic, Pacific, and Gulf Coasts, while research in physical oceanography, submarine geology, geophysics, and marine meteorology is sponsored by various Federal agencies. As a result the total income of the institutions carrying on oceanographic research is now in the neighborhood of \$2,300,000, or three times the sum required to maintain the pre-war level of activity and five times the amount now available in unrestricted funds.

The effects of this great outpouring of money from State and Federal sources are not entirely healthy. No one knows how long it will last or what direction the required investigations will take. The projects must be manned by people with specialized training, yet very few have tenure. In securing workers there is no large field of employment to be drawn on and into which they can return if the work is terminated. Hence such adjustments must be borne by the regular staffs of the oceanographic laboratories and by budgets which are disproportionately small. These uncertainties tend to discourage able men from work on Government-financed projects.

Secondly, oceanography is not developing in a well-balanced manner. The attitude of the men having responsibility for the assignment of Government funds has been very liberal. The direction of the research and, to a considerable extent, even the choice of projects have been left to the staffs of the various laboratories. However, there is no one agency in the Government which clearly has the responsibility for a balanced development of marine science. In consequence, broader biological and chemical problems have taken second place to the physics and geology of

the sea. The directors of the laboratories are very much aware of this situation, but the fact remains that with the exception of the applied fisheries investigations there is almost no financial support in this country for general marine biology.

Free development of the science is also hindered by the inequality of the restricted and unrestricted funds. With few exceptions, the senior men who knew something about oceanography before the war have all had to take on administrative duties. Although this is no doubt generally true of science in this country today, it is particularly acute in oceanography where expansion has been so rapid. The effort of the younger scientists also is of necessity deflected in directions where funds are available. In consequence, inadequate thought is being given to those problems which do not have military applications or do not bear on specific fisheries.

Most of the assured income of the laboratories is now committed to maintain the salaries of their basic staffs, and to provide fellowships and laboratory facilities for those not working on the Government programs. Only very minor sums remain for new investigations at sea. Shortage of un-

restricted funds also limits the use of the shop facilities for the development of instruments and equipment except for special work under Government contract. This is seriously handicapping basic investigations.

In brief, oceanography does not at present need and probably could not effectively use very much larger sums than are now available. It does need, however, a larger proportion of its funds in the form of assured income for the general purposes for which the oceanographic laboratories were founded, to give greater stability to oceanography as a career, to correct the balance between basic and applied research, and to establish a firmer base to support work done on short-time Government contracts and appropriations. To accomplish this, the assured income of the oceanographic laboratories should be increased sufficiently to permit them to operate independently at least at the pre-war level of activity. If, in addition, encouragement were given to universities to extend the teaching of oceanography, and if a limited number of fellowships were available to permit able students to undertake the study, a healthy development of the subject would be assured.

CONCLUSIONS AND RECOMMENDATIONS

THE COMMITTEE believes that the oceanographic sciences offer a rich and promising field for research. Continued progress is essential not only to increase man's understanding of the world in which he lives, and its biological processes, but also as a basis for the exploitation of the untapped resources of the oceans. To insure this progress both private and public support are needed to provide the stability and freedom prerequisite to basic scientific advances. Government support on a liberal and farsighted basis should continue to provide the extensive coordinated effort demanded by the size and complexity of oceanic phenomena.

The Committee recommends that a determined effort be made to secure private funds for the following specific purposes:

1. *Provision of research fellowships, at both pre- and post-doctoral levels, at existing oceanographic institutions.* Such fellowships would enable young people trained in the basic sciences to use their abilities and experience on research in oceanography. Many of the recipients of such fellowships may be confidently expected to gain a permanent interest in and understanding of problems of the sea, and to make these problems a lifelong focus of their research work. Because of the specialization involved in oceanographic research and the time required to bring a research problem to a successful conclusion, these fellowships should be for at least two and preferably three years.

2. *Provision for visiting investigators both from American colleges and abroad.* If it were possible to furnish adequate laboratory facilities and ships services to visitors at the existing laboratories, new ideas and advances in the basic sciences would quickly be applied to the ocean. Thus the isolation of these laboratories because of their location at the water's

edge would in large part be overcome. Before this becomes feasible it will be necessary to alleviate the overcrowded conditions of laboratory buildings and to endow the unrestricted operations of the ships, at least in part.

3. *Provision of permanent positions for research workers in the oceanographic sciences.* By far the greater part of oceanographic research is now supported by contract funds on a relatively short-term basis. As a result, commitments cannot be made for new positions with tenure at the oceanographic institutions despite the large increase in the numbers of persons engaged in oceanographic research. Consequently, considerable difficulty exists in attracting and holding research workers of the highest caliber. This situation should be remedied both by increasing the number of permanent staff positions at the oceanographic institutions and by providing faculty positions in universities.

4. *Provision for support of research in basic aspects of biological and chemical oceanography.* These fields are not now receiving adequate support from government sources primarily because of their lack of immediate importance to military or fisheries problems. They present, however, many of the most challenging and promising problems of the sea.

5. *Support of high seas exploratory expeditions.* The development of new methods for sounding and navigation, for geophysical and geological exploration of the sea bottom, for measuring currents and properties of ocean waters, and for collecting and studying marine organisms has proceeded very rapidly during the past ten years. Because of lack of funds these methods have so far been applied primarily to relatively nearshore waters. These new tools should be used for exploration of the entire oceans. With oceanographic

ships and manpower presently available annual exploring expeditions of at least three months' duration could be carried out in both the Atlantic and the Pacific over the next five years, and would almost certainly yield results of importance in understanding the history of the earth and the physical and biological processes in the sea.

To put these recommendations into effect the additional sums required annually are estimated, at present day costs, to be as follows:

To establish research fellowships.....	\$ 25,000 — \$ 50,000
To establish staff and faculty positions.....	100,000 — 150,000
Unrestricted funds to operate ships.....	125,000 — 150,000
Basic research in biology and chemistry.....	200,000 — 250,000
Expeditions	50,000 — 150,000
Total.....	\$500,000 — \$750,000

In addition, new laboratory construction will be required to replace temporary quarters now occupied at various laboratories.

These recommendations are based on the assumption that Federal and State support of oceanographic research will remain at the present level for the foreseeable future. Concerning Federal support the Committee recommends:

1. That present support of private oceanographic institutions be continued on as broad a basis and with as much continuity as possible.

2. That agencies of the Federal Government conducting oceanographic work should increase the amount of effort devoted to basic research and to long-term scientific objectives in addition to carrying out ocean surveys and work of immediate practical application.

3. That oceanographers employed in the Federal Government under Civil Services

should be assigned to work from time to time at one of the major oceanographic institutions. By actual participation in research on the frontiers of oceanography their insight would be quickened and their interest refreshed. At the same time, their colleagues on the staffs of the oceanographic institutions would gain by contact with practical problems which are of primary concern to the Government agencies.

4. That through the United Nations and the Point Four program the United States

should encourage the rebuilding and development of oceanographic research centers in other countries, particularly in the southern hemisphere and the western Pacific. Because of the unity of the oceans, the interests of the United States would be well served by developing oceanographic centers in other countries which could co-operate with our own oceanographic agencies in coordinated exploratory programs.

If funds become available for fellowships and for expeditions, these might appropriately be administered by the National Academy of Sciences, the National Research Council, or the National Science Foundation. In addition it would appear desirable that continuing surveys be made from time to time of the progress of the oceanographic sciences, and these could be carried out by this Committee.

The Committee recommends that it be continued for this purpose.

APPENDIX

PRESENT FACILITIES FOR OCEANOGRAPHIC RESEARCH IN THE UNITED STATES

THE REPORT of the earlier Committee on Oceanography of the National Academy of Sciences submitted in November 1929, and published in part in a book by H. B. Bigelow entitled "Oceanography, Its Scope, Problems and Economic Importance," marked a turning point in the development of oceanography in America. It resulted directly in the substantial endowment of the subject from private sources at two universities, California and Washington, and in the endowment of research institutions at Woods Hole and Bermuda. Oceanography thus received recognition as an established branch of the natural sciences, and a limited number of scholars were enabled to pursue their studies without the restrictions inherent in public service. This impetus led to the establishment of a number of additional centers for oceanographic study during the last twenty years. The present facilities for research and teaching, which have come into being or have achieved substantial development as a sequel to the action by the National Academy in 1927, are described below.

THE SCRIPPS INSTITUTION OF OCEANOGRAPHY

The Scripps Institution of Oceanography is the outgrowth of investigations begun in 1892 by the Department of Zoology of the University of California under the leadership of Professor W. E. Ritter. With support from Miss E. B. Scripps and Mr. E. W. Scripps the enterprise was carried on as a private foundation until 1912 when it became part of the University of California, the Scripps Institution for Biological Research. The scope and character of the research program ultimately focused on all

aspects of the study of the sea, a fact formally recognized in 1925 when the name was changed to the Scripps Institution of Oceanography.

The principal laboratory building on the campus at La Jolla was built in 1931 with funds provided by the Rockefeller Foundation. Other permanent buildings include a smaller laboratory built in 1910, the library in 1916, and a public museum and aquarium in 1950. More than half of the available floor space of the Institution is in temporary wooden structures, chiefly on the grounds of the Navy Electronics Laboratory at Point Loma. Among the principal physical assets of the Institution are four research vessels ranging in length from 85 to 143 feet, three of which have been acquired since the war, in part because of contracts. One of these, a converted navy tug, is capable of work at sea anywhere in the Pacific.

The basic annual budget of the Institution is approximately \$270,000. Ninety percent is contributed by the State of California through legislative appropriations to the University, and the remainder comes from the endowment established by the Scripps family. During the last three years an additional \$400,000 per year has been received from the State for research on the California sardine fishery and approximately \$300,000 per year has been derived from contracts with the Federal Government and other agencies.

Of the 250 employees on the year-round staff, sixteen are members of the faculty of the Department of Oceanography in the Graduate School of the University of California, and some thirty others are qualified for independent research.

In addition to its research activities the Institution is the principal world center for training oceanographers. In 1949-1950 over 50 graduate students were registered in the Department of Oceanography, and eight others were working on theses sponsored by other departments of the University. Within the last few years students from France, Holland, Argentina, Peru, Egypt, China, South Africa, Canada, and the Philippines have taken advanced degrees in oceanography or related sciences at the Institution. The Institution uses a portion of its budget each year to support visiting scientists from other universities in the United States and abroad.

Longer papers resulting from the Institution's research are published by the University of California press, chiefly in the *Bulletin of the Scripps Institution of Oceanography, Technical Series*. Most reports, however, are published in scientific journals. Reprints of these are bound annually in a volume of *Contributions from the Scripps Institution of Oceanography* and distributed to libraries and research institutions throughout the world. There were 434 contributions from 1936 to the end of 1949.

THE BERMUDA BIOLOGICAL STATION FOR RESEARCH, INC.

The Bermuda Biological Station for Research was founded in 1903 and incorporated in the State of New York in 1926. The Trustees, however, are from Canada, Bermuda, England, and the United States. The annual income is about \$35,000, of which some \$5,000 is derived from endowment by the Rockefeller Foundation, \$11,200 from annual grants by the Bermuda Government for maintenance and fisheries research, and the remainder from rents, fees, and other sources.

Living and working facilities are provided for a small permanent staff and for visiting investigators. The Station serves as an oceanic base for the Woods Hole Oceanographic Institution and at times it serves as the official marine laboratory of the Bermuda Government. Present facilities

permit most types of research in inshore waters. Efforts are being made to secure a sea-going vessel and additional funds for the study of the productivity of open ocean waters, the physiology of deep sea forms, and the circulation of the North Atlantic.

OCEANOGRAPHIC LABORATORIES OF THE UNIVERSITY OF WASHINGTON

Partly as a result of the impetus received from the Committee on Oceanography of the National Academy of Sciences, the Oceanographic Laboratories of the University of Washington were founded in 1930. With the aid of funds from the Rockefeller Foundation, a three-story laboratory was built in Seattle, and a small research vessel was acquired. The parent organization was the Puget Sound Biological Station, founded in 1906 at Friday Harbor by Professors Kincaid and Frye of the University of Washington. This station was expanded and rebuilt in 1926 on a 500-acre tract near Friday Harbor. It consists of six one-story laboratory buildings, living accommodations for 150 people, a machine shop, boat house, and pier.

The permanent scientific staff of the Oceanographic Laboratories is made up chiefly of faculty members from other departments of the University of Washington, including those of chemistry, biochemistry, physics, zoology, botany, geology, meteorology, fisheries, and microbiology. Three faculty members have recently been appointed directly to the staff of the Laboratories without other responsibilities in the University. The remainder of the staff consists of four professional scientists and about twenty technical and administrative personnel including twelve to fifteen part-time graduate assistants.

At the present time the University is establishing a Department of Oceanography which will present courses of instruction at the undergraduate and graduate level leading to degrees in oceanography.

The Laboratories were closed during the war and its vessel sold. Since then field work has been dependent on small chartered vessels and on a boat belonging to

the School of Fisheries at the University of Washington. A larger vessel has recently been provided and will permit the re-establishment of a research program at sea.

The basic annual budget of the Laboratories has been about \$70,000, appropriated by the State of Washington through the University, and an approximately equal sum has been obtained from Federal and other contracts. However, additional funds from governmental agencies are to be anticipated to support the investigations of the new Department of Oceanography.

The results of research studies are reported in the *Supplementary Series of the Oceanographic Laboratories* and comprise reprints appearing in scientific journals. This series includes about 150 reports. Monographic papers appear in *Publications in Oceanography*, fourteen of which have been published.

THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

The Woods Hole Oceanographic Institution was established in 1930 as a corporation in the Commonwealth of Massachusetts. It is managed by a Board of Trustees on which men of science and men of affairs, selected because of special interests in oceanography, are balanced.

The Institution is supported by endowment of \$2,500,000, chiefly from the Rockefeller Foundation, but supplemented by gifts from the Carnegie Corporation and private donors. Its annual income is approximately \$140,000. In addition it expends annually some \$800,000 derived from governmental and other contracts.

In addition to a laboratory building, now greatly overcrowded, the Institution owns and operates two ships suitable for extended work at sea and several smaller vessels adequate for work along shore.

Originally the staff was recruited from the faculties of universities and was in residence chiefly during the summer. The Institution consequently afforded facilities for oceanographic research and for graduate training for various universities. More recently a limited staff has been retained

throughout the year while others work full time on governmental contracts. However, the policy of cooperation with the universities through part-time appointments continues. The work of the staff is directed only insofar as the obligations of contracts demand, or as is implied in the selection of staff members, and as is necessary in coordinating the use of the research vessels.

The Institution publishes, in collaboration with the Massachusetts Institute of Technology, a serial entitled *Papers in Physical Oceanography and Meteorology*. Most reports, however, appear in the regular periodicals devoted to biology, chemistry, geophysics, geology, and meteorology. Reprints of these are bound in an annual volume for distribution without charge to nearly 600 libraries throughout the world. Five hundred and fifty contributions had been issued by the end of 1950.

BINGHAM OCEANOGRAPHIC FOUNDATION AND SEARS FOUNDATION FOR MARINE RESEARCH AT YALE UNIVERSITY

The Bingham Oceanographic Foundation was established in 1930 by endowment from Mr. Harry Payne Bingham to care for the oceanographic collections made by Mr. Bingham in 1925-27, and to maintain the Bingham Oceanographic Laboratory for oceanographic and marine biological research. Permanently associated with the Bingham Oceanographic Foundation is the Sears Foundation for Marine Research, established in 1937, which is intended to support publications in oceanography and marine biology. The *Bulletin of the Bingham Oceanographic Collection*, now in its twelfth volume, is devoted to the publication of the results of investigations, primarily biological, under the Bingham Foundation. The *Journal of Marine Research*, under the Sears Foundation, is the principal medium for the publication, in this country, of shorter articles dealing with the interpretation and understanding of the sea in all its aspects. Also published under this Foundation are the *Memoir Series* for works

of monographic proportions. The first of these, "Fishes of the Western North Atlantic—Part I: Lancelets, Cyclostomes and Sharks," appeared in 1948 and will soon be followed by succeeding volumes on fishes and other subjects.

As the result of these Foundations, Yale has become the most active university center for formal training in biological oceanography in the East. Graduate students enrolled for the Ph.D. degree in the Departments of Zoology and Botany at Yale may take special courses and do research in oceanography, ichthyology, or marine biology under the supervision of the ten members of the staff.

The Laboratory does not maintain an oceanographic vessel, but work at sea is done through cooperative arrangements with the U.S. Fish and Wildlife Service, the Woods Hole Oceanographic Institution, the Connecticut State Board of Fisheries and Game, private individuals, and the temporary charter of fishing boats.

The annual income presently available for work under these Foundations is as follows:

Bingham Foundation Endowment	\$ 3,500
Yale University general funds	23,000
Sears Foundation	2,400
Other	5,000

Total	\$33,900

UNIVERSITY OF RHODE ISLAND

The University of Rhode Island has maintained for some years the Narragansett Marine Biological Laboratory on Narragansett Bay for the study of local fisheries problems. In 1949 a graduate training program leading to the masters degree at the end of two years in biological oceanography was established with the intention of training a limited number of students for research in oceanography or for the fisheries service. The first year is spent in residence at the University; the second in gaining field experience through cooperative arrangements with the Fish and Wildlife

Service and the Woods Hole Oceanographic Institution.

The funds available for this development are at present:

University of Rhode Island	\$20,300
Office of Naval Research	7,500
Other	1,000

Total	\$28,800

HARVARD UNIVERSITY

Harvard University has played a prominent role in the development of oceanography in the United States through the leadership of Alexander Agassiz and Henry B. Bigelow and their associates at the Museum of Comparative Zoology. The Museum maintains curatorships and a Fellowship in Oceanography. Several members of the University faculty hold part-time appointments at the Woods Hole Oceanographic Institution. Recently oceanography has been recognized as a field of study through the appointment of a Standing Committee of the Faculty charged with caring for the interests of students in biology, geology, or other departments who wish to make oceanographic work their specialty.

BROWN UNIVERSITY

On a trial basis Brown University has recently appointed (1949) a visiting Professor of Oceanography to give an introductory course in oceanography and meteorology, as well as to supervise advanced study.

LAMONT GEOLOGICAL OBSERVATORY OF COLUMBIA UNIVERSITY

At Columbia University the establishment of the Lamont Geological Observatory at Palisades, New York, has recently roughly doubled the space available to the Department of Geology, and much of it is being used for investigations of the ocean basins through the application of modern geophysical techniques. Its work is chiefly dependent on contracts with the Navy and other temporary funds. Much of the field work is

carried out in close cooperation with the Woods Hole Oceanographic Institution.

DEPARTMENTS OF METEOROLOGY AND APPLIED MATHEMATICS OF NEW YORK UNIVERSITY

At New York University, with the support of the Beach Erosion Board and the Office of Naval Research, methods of forecasting ocean waves and surf from synoptic weather data are being studied in the Department of Meteorology, and theoretical problems concerning the transformation of waves in shallow water are being investigated in the Institute of Applied Mathematics. Several students are at present working towards advanced degrees in physical oceanography.

CORNELL UNIVERSITY

In recognition of the necessity for a knowledge of oceanography in conservation work in marine fisheries, the Department of Conservation at Cornell University has maintained an oceanographer on its staff since 1949.

CHESAPEAKE BAY INSTITUTE

Chesapeake Bay and its estuaries are the principal avenue of commerce for bordering communities, and a medium for disposal of the waste of major industries. In addition, the Bay provides a resort area for vacationing city dwellers. Crabs, oysters and fish of the Bay provide a major livelihood for the peoples of Maryland and Virginia. During the past fifty years the oysters and some of the fish have become badly depleted, resulting in poverty and decay of many once prosperous communities.

The problem of maximum utilization of Chesapeake Bay for human benefit cannot be solved without a more comprehensive understanding of the physical, chemical, geological, and biological processes in the Bay. Accordingly, in 1948 the states of Maryland and Virginia, in cooperation with the Office of Naval Research and the United States Fish and Wildlife Service, sponsored the establishment at the Johns Hopkins University of the Chesapeake Bay Insti-

tute, to be supported initially by funds from the two states and from the Navy, and eventually, it is hoped, at least in part from private endowment funds.

At present, the annual budget of the institute is approximately \$100,000, contributed in equal parts by the states of Maryland and Virginia and the Office of Naval Research.

An adequate laboratory building has been acquired at Annapolis to house the small professional staff, and a specially designed research vessel, the *Matthew Fontaine Maury*, has been constructed. Close cooperation with the state biological laboratories of Maryland and Virginia, as well as with faculty members from several departments of the University is maintained.

UNIVERSITY OF MIAMI MARINE LABORATORY

The University of Miami, through the staff at its Marine Laboratory, offers instruction in marine biology, fisheries, and other phases of oceanography, including geology. Research in these fields is conducted by the permanent staff in the coastal waters of Florida and to a lesser extent in other parts of the Gulf of Mexico and the Caribbean. Three motor boats are maintained for coastal work and others are chartered from time to time for more extensive work at sea.

The marine fishery program is supported partially by the Florida State Board of Conservation, and partially by smaller sums from various West Indian government agencies. It is concerned with the fisheries characteristic of sub-tropical Atlantic waters. In cooperation with the U.S. Fish and Wildlife Service, the Atlantic States Marine Fisheries Commission, the Gulf States Marine Fisheries Commission, State fishery agencies, West Indian government agencies, and the fishing industry, the Marine Laboratory conducts annual sessions of the Gulf and Caribbean Fisheries Institute to exchange information on problems of the sports and commercial fisheries of the region.

Funds for practical problems such as marine borer damage and pollution are provided through short term grants and contracts with various federal and municipal agencies, including the U.S. Navy. Other funds are derived from gifts from industry and private individuals. The annual income available for the support of the Marine Laboratory is approximately as follows:

State of Florida.....	\$45,000
(renewable biennially)	
Federal agencies (short term)....	30,000
Other governments and municipal agencies	10,000
Gifts, industrial grants and general funds of the University.....	45,000
Total.....	\$130,000

DEPARTMENT OF OCEANOGRAPHY AT THE AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS

The low-lying, irregular coast, broad and shallow continental shelves, and peculiar meteorological conditions of the Gulf of Mexico give rise to a special set of oceanographic problems of importance both to the fishing industry and to oil companies searching for and producing oil from beneath the sea floor. To fulfill the needs for trained men and for research on these local problems the Agricultural and Mechanical College of Texas assembled a small staff and established a Department of Oceanography in 1949. The staff works closely with the Texas Agricultural and Mechanical Research Foundation on such problems as the causes of the decline in the Louisiana oyster fishery and the wave and current conditions encountered by undersea pipe lines. Recently a program of basic research in physical oceanography of the waters of the entire Gulf of Mexico has been initiated. A vessel of the Fish and Wildlife Service is available for this work.

**HANCOCK FOUNDATION OF THE
UNIVERSITY OF SOUTHERN CALIFORNIA**
The Hancock Foundation of the University of Southern California has ample labora-

tory space on the campus of the University in Los Angeles, and operates a large research vessel for studies in the waters off Southern California and northern Mexico. Its small permanent staff is made up primarily of biologists concerned with taxonomic and evolutionary problems, but it has also supported research in bacteriology, engineering, and especially submarine geology.

DEPARTMENT OF ENGINEERING, UNIVERSITY OF CALIFORNIA, BERKELEY

Research on shore line processes and ocean waves has been conducted for some years by the Department of Engineering of the University of California at Berkeley. Field observations and hydraulic model studies, as well as the development of instrumentation, are now being supported by contracts with the Office of Naval Research and the Beach Erosion Board. The total annual budget is approximately \$40,000 a year.

HAWAII MARINE LABORATORY

The Hawaii Marine Laboratory is an integral part of the University of Hawaii. Its central Pacific location naturally focuses attention on the rich but relatively unstudied tropical sea and the many related problems in marine biology and oceanography. Facilities include classrooms and laboratories on the campus of the University in Honolulu, a marine laboratory at Waikiki Beach, and more extensive provisions for marine research at Coconut Island, Oahu. The latter consists of a laboratory building with provisions for accommodating twenty investigators, equipment for biological and physiological research, and a 46-foot research vessel.

The University offers courses of instruction leading to both undergraduate and graduate degrees in marine zoology. The staff includes ten scientists competent particularly in zoology, botany and fisheries biology. Training in the practical aspects of marine zoology is enhanced by association with the fisheries investigations of the Territorial Division of Fish and Game and

the Pacific Oceanic Fishery Investigations. Fellowships are available through the University and the Pacific Oceanic Fishery Investigations.

OCEANOGRAPHIC WORK OF THE FEDERAL GOVERNMENT

Between the two world wars the oceanographic activities of the Federal Government were concentrated on work of immediate importance to navigation, principally surveying and charting of the sea bottom and measurements of tides and currents in inshore waters. The work was conducted by three agencies: the Coast and Geodetic Survey of the Department of Commerce, the Hydrographic Office of the Navy, and the United States Coast Guard. At first detailed bottom surveys were made only in waters less than 100 fathoms deep and in near-shore areas. After the development of echo sounding, it became possible to extend surveys out into waters more than 1,000 fathoms deep 200 miles or more from shore. Tide and current measurements were also made at localities important for navigation and were used in the preparation of daily predictions. Observations of temperature and salinity in the northwestern North Atlantic for use in computing the currents to predict the probable paths of icebergs were made by the United States Coast Guard as part of its work in conducting the International Ice Patrol.

Since World War II the oceanographic activities of the Federal Government have greatly increased both in scope and magnitude. Charting of ocean depths using recording echo sounders and modern electronic aids to navigation has continued, and several new types of work have been undertaken. The Navy has taken the lead in these new developments, in part through the Hydrographic Office and the various Navy laboratories, and in part through support of research in universities, oceanographic institutions, and other civilian organizations by the Office of Naval Research and the Bureau of Ships.

Within the Hydrographic Office, the new Division of Oceanography has assumed a

major share of the responsibility for descriptive oceanographic work in areas not being surveyed by other agencies, for preparation of charts showing conditions in the ocean, and for coordinating special research at sea. Because of limitations of personnel, ships, and funds, its efforts to date have been confined chiefly to the North Atlantic, but it has sponsored work elsewhere, notably in the Arctic, Antarctic and Mediterranean. It is a depository for oceanographic information of all kinds from American naval and merchant vessels, including bathythermograph records, echo soundings in deep water, current and surface temperature observations, and other records such as the occurrence of discolored water.

Since jurisdiction over local sea fisheries usually lies with the state governments, the maritime states support research programs. These are variously conducted by state conservation agencies, by state universities, and by privately endowed research institutions. The Federal government conducts research on fisheries of territorial waters, or those whose range is interstate or international. It generally initiates a research program only when so directed by Congress. International commissions are established for study and regulation of the fisheries for Pacific halibut, Pacific tunas, and the fisheries of the northwest Atlantic.

The Fish and Wildlife Service of the Department of the Interior has expanded its oceanographic work. In Honolulu it has recently built a large laboratory on the campus of the University of Hawaii, where a staff of over 90 people is employed to assay the potentialities of the pelagic fisheries of the central north Pacific and to study the ecology of the fishery stock in that area. At Stanford University and at Point Loma, California, are laboratories where it conducts its part of the cooperative sardine research program, in which the California Division of Fish and Game, the California Academy of Science, the Scripps Institution of Oceanography, the Fishery Board of Canada, and others participate. The Fish and Wildlife Service

operates one of the four vessels working in this program. In the Gulf of Mexico, a new laboratory has recently been established at Galveston, where a large research vessel operates to study the productivity of the Gulf from a fishery point of view. Here a cooperative program is evolving in which all institutions interested in marine studies are invited to participate. At Sarasota, Florida, are a small laboratory and vessel devoted to investigating the causes of periodic swarming of plankton organisms, particularly of species causing the so-called "red tide" which is occasionally so destructive to fish and invertebrates. In New England waters a new small research vessel has recently been commissioned to study the ecological causes of fluctuations of oyster population in Long Island Sound. At Woods Hole is centered the research program which the United States conducts as a member nation of the International Commission for the Northwest Atlantic Fisheries, with one sea-going vessel.

Finally, the Beach Erosion Board of the Army's Corps of Engineers is conducting

oceanographic research on waves and other processes of importance to shore erosion and its control, and is sponsoring research by universities. Research on the phenomena of the boundary layer between atmosphere and ocean and on sea ice is being sponsored by the Air Force.

Any listing of the facilities for the development of the marine sciences in this country is in danger of giving a false impression of adequacy. With the exception of the groups at Woods Hole and La Jolla, each unit is small and several of them are only a few years old. To a large degree they are dependent on government support of a short-term nature. Much of the work is aimed at local problems or at problems having immediate application. When the size of the oceans is borne in mind and it is remembered that oceanography attempts to deal with the biology and chemistry as well as the physics and geology of the seas, it can be seen that the establishments supporting the present national effort in oceanography are probably inadequate.

